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GROUND SUPPORT PREDICTION MODEL

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Jacobs Associates

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GROUND SUPPORT PREDICTION MODEL

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13 ABSTRACT

This is the second phase of a two year research project to develop a tunnel support prediction model based on known geologic factors determined by pre-construction geologic investigation. Phase I was fully described in the final report for contract H0210038. Under phase I a detailed study was made of 33 case study tunnels, comparing geologic and construction factors with actual support systems used. From this a tentative empirical relationship was suggested. This concept called the Rock Structure Rating (RSR) places numerical ratings on geologic factors, the sum of which gives a relative index of the ability of the rock to support itself around a tunnel opening.

The work described in this report covers the first six months of phase II, where the work previously performed is being extended with additional empirical, theoretical and experimental capability to confirm, expand or modify the ground support prediction model. Five additional case studies are described and compared to the prediction model. A report is given on a plan for incorporating ideas and suggestions from several selected individuals of various disciplines of the tunneling industry, through personal contact and explanation of work performed to date. A copy of the questionnaire sent to these individuals is included. Also described are plans for applying the final prediction model to ongoing tunnel projects to field test the concept.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	W
Rock Structure Rating (RSR)						
Rib Ratio (RR)						
Tunnels (Rock)						
Rapid Underground Excavation						
Geologic Predictions						
Ground Support Systems						

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TECHNICAL REPORT SUMMARY

The objective of this research project (contract H0220075) is to gather additional tunnel case history data, analyze such data with respect to geologic and construction factors and by comparison and correlation to support systems evolve and propose a support prediction model. A prediction method involving an empirical relationship between geologic factors and support, known as the Rock Structure Rating (RSR) concept was developed in the first year of this two-year endeavor. This is described more fully in Section 1, and the final report of contract H0210038 (Ref. 1)

The work of the second year is divided into three parts. Some work has been performed on each of these to date.

The first portion is devoted to acquiring additional case studies to supplement those used in the original development of the RSR concept. Five tunnels have been analyzed for this purpose and described in Section 2. Data for ten additional studies has been acquired to complete this work.

The second portion of the work is to acquire a sampling of industry acceptance of the proposed prediction method and to investigate and incorporate suggested changes in the method. Section 3 describes the methods used by which responses from thirty selected people in various disciplines of the tunneling industry were elicited. Brief comments are made regarding responses returned to date.

The final phase of the work is to incorporate the additional data acquired to confirm, expand or modifty the precition model and to field test it by application to ongoing tunnel projects. Section 4 describes the work begun on this phase, including two joint field trips, preliminary support estimates on four tunnels and comparison of the estimated and actual supports

on the New Melones Tunnel.

Work under all three phases of the research will continue during the next six months. Data obtained from analysis of the remaining case studies will be added to the original 33 to redevelop an empirical relationship. When all questionnaires have been returned they will be summarized and all pertinent suggestions considered for inclusion or modification of the prediction model. Using the modified model, ongoing tunnel projects will be analyzed and support predictions made and compared to actual supports placed.

1.0 INTRODUCTION

1.1   Objectives

Despite many advances in rock mechanics, geological investigations and use of in situ instrumentation; the determination and/or prediction of ground support for rock tunnels remains more of an "art" than a science. There are many construction, contractural and geologic factors which affect and complicate the problem and which must be considered individually and collectively in arriving at realistic solutions. The object of the overall research program is two fold: 1) Provide a meaningfull method by which engineers, geologists and contractors can appraise the need for ground support in future tunnels on a common basis and 2) Provide a means by which data, pertinent to the support problem can be similarly obtained, evaluated and subsequently correlated between tunnel projects.

1.2   Review of Previous Research

Under Phase I of the research effort, a methodology called Rock Structure Rating (RSR) (Ref.1) was developed. This concept, which was based on case history studies of 33 tunnels, rates various weighted combinations of geologic factors on a scale of 0 to 100. (See Fig. 1.1) The higher the RSR value, the greater the relative ability of the rock to support itself around a tunnel opening. The lower the value, the more dependent is the rock on a supplementary reinforcement or support system.

Since most of the tunnels investigated had used steel rib supports it was decided to make comparison of support requirements on this basis. The method developed for this correlation is called the Rib Ratio (RR). Each rib support system actually used is compared to a common datum. That

BASIC ROCK TYPE	GEOLOGICAL STRUCTURE			
	MASSIVE	SLIGHTLY FAULTED OR FOLDED	MODERATELY FAULTED OR FOLDED	INTENSELY FAULTED OR FOLDED
IGNEOUS	30	26	15	10
SEDIMENTARY	24	20	12	8
METAMORPHIC	27	22	14	9

ROCK STRUCTURE RATING
PARAMETER "B"
JOINT PATTERN
DIRECTION OF DRIVE

AVERAGE JOINT SPACING FEET	STRIKE ⊥ TO AXIS					STRIKE ∥ TO AXIS		
	DIRECTION OF DRIVE					DIRECTION OF DRIVE		
	BOTH	WITH DIP		AGAINST DIP		BOTH		
	DIP OF PROMINENT JOINTS					DIP OF PROMINENT JOINTS		
	FLAT	DIPPING	VERTICAL	DIPPING	VERTICAL	FLAT	DIPPING	VERTICAL
<.5 (CLOSELY JOINTED)	14	17	20	16	18	14	15	12
.5-1.0 (MODERATELY JOINTED)	24	26	30	20	24	24	24	20
1.0-2.0 (MODERATE TO BLOCKY)	32	34	38	27	30	32	30	25
2.0-4.0 (BLOCKY TO MASSIVE)	40	42	44	36	39	40	37	30
>4.0 (MASSIVE)	45	48	50	42	45	45	42	36

Flat $0° - 20°$
Dipping $20° - 50°$
Vertical $50° - 90°$

ROCK STRUCTURE RATING
PARAMETER "C"
GROUND WATER
JOINT CONDITION

ANTICIPATED WATER INFLOW (gpm/1000')	SUM OF PARAMETERS A + B					
	20-45			46-80		
	JOINT CONDITION					
	1	2	3	1	2	3
NONE	18	15	10	20	18	14
SLIGHT (200 gpm)	17	12	7	19	15	10
MODERATE (200-1000 gpm)	12	9	6	18	12	8
HEAVY (>1000 gpm)	8	6	5	14	10	6

Joint Condition:
1 - Tight or Cemented
2 - Slightly Weathered
3 - Severely Weathered or Open

Figure 1.1

datum is a theoretical rib support that would be required for a similar sized tunnel driven through a uniform soft ground structure as determined by using Terzaghi's empirical formula (p.63, Ref. 2). The Rib Ratio is the amount of support actually installed as a percentage of the datum requirement. Thus a high Rib Ratio indicates a proportionally greater amount of support than a low Rib Ratio. Since the datum condition considers a tunnel of equal size to the actual, this most important construction parameter has been incorporated into the concept.

Approximately 90 suitable geologic-support situations were obtained from the case studies and plotted on a graph (See Fig. 1.2). The equation of a parabolic curve plotted on these points represents the suggested tentative empirical relationship between geologic factors (RSR) and required support (RR). This equation is: $(RR + 70) (RSR + 8) = 6000$. Using this relationship, Support Requirement Charts were developed for various size tunnels. See Fig. 1.3 for a typical chart based on a 20 foot diameter tunnel. The interraction of either rock bolts or shotcrete with the rock is far more complicated than rib support, and only partially understood. The implied relationship between rock bolt and shotcrete support and rock loads indicated by the charts is offered only as an approximate correlation.

Phase I also involved the investigation of possible new and innovative support systems. The new concepts were compared with the conventional support systems on the basis of suitability and cost. For those interested in more detail on Phase I it is available in the final report (Ref. 1). A synopsis of the work performed for the RSR concept was presented as a paper to the Rapid Excavation and Tunneling Conference (Ref. 3).
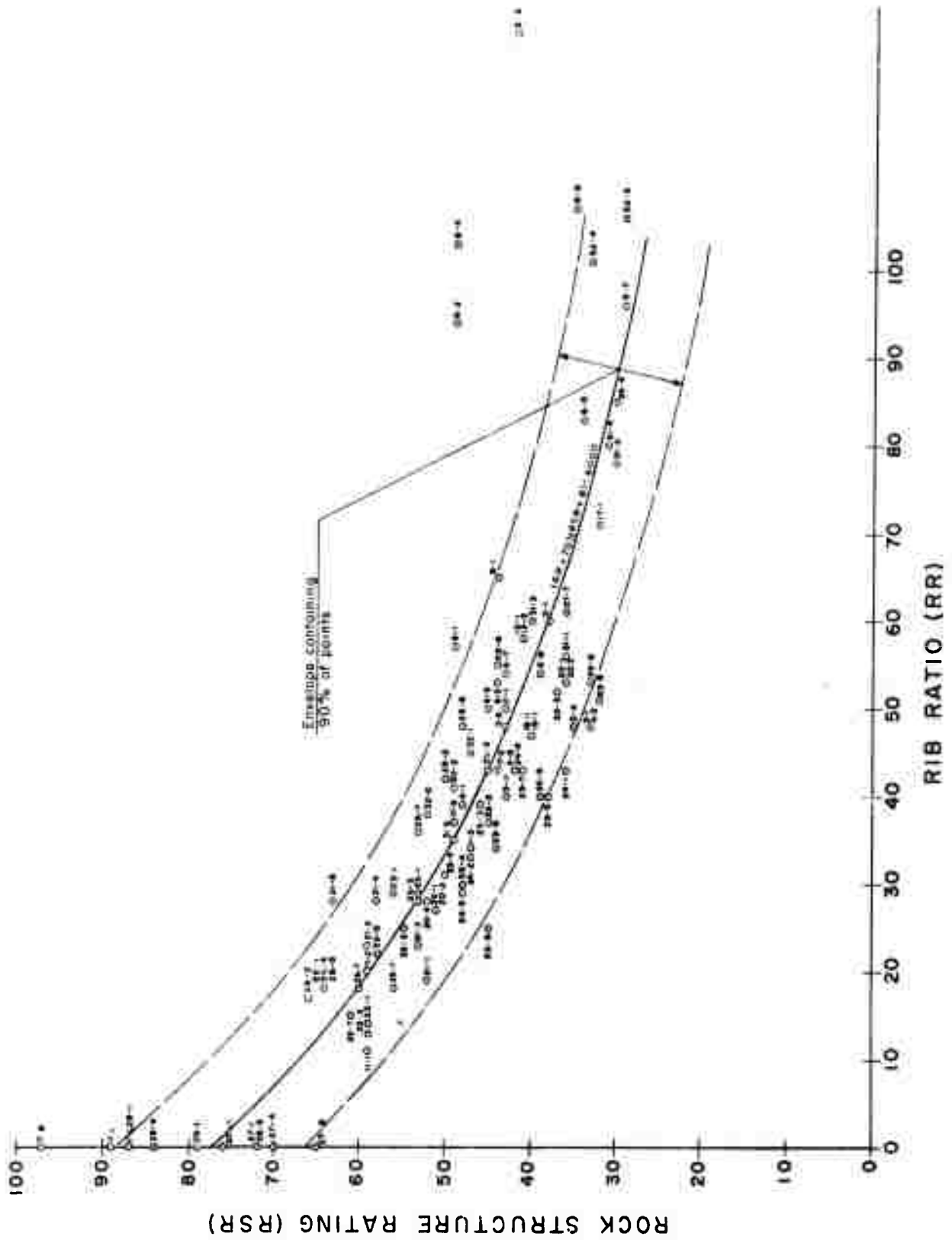
Figure 1.2

SUPPORT REQUIREMENT CHART

1" Diameter Rock Bolts

$$s = \sqrt{\frac{2.4}{Wr}}$$

Shotcrete

$$t = 1" + \frac{Wr}{1.25}$$

6H20 RIB

8WF31 RIB

8WF48 RIB

Practical Limit For Rib And Bolt Spacing

Datum (Rib Ratio = 100)

ROCK LOAD (K/Sq Ft) (Wr)

0.5
1.0
1.5
2.0
3.0
4.0
5.0
6.0
7.0

70
60
50
40
30
20
10

ROCK STRUCTURE RATING
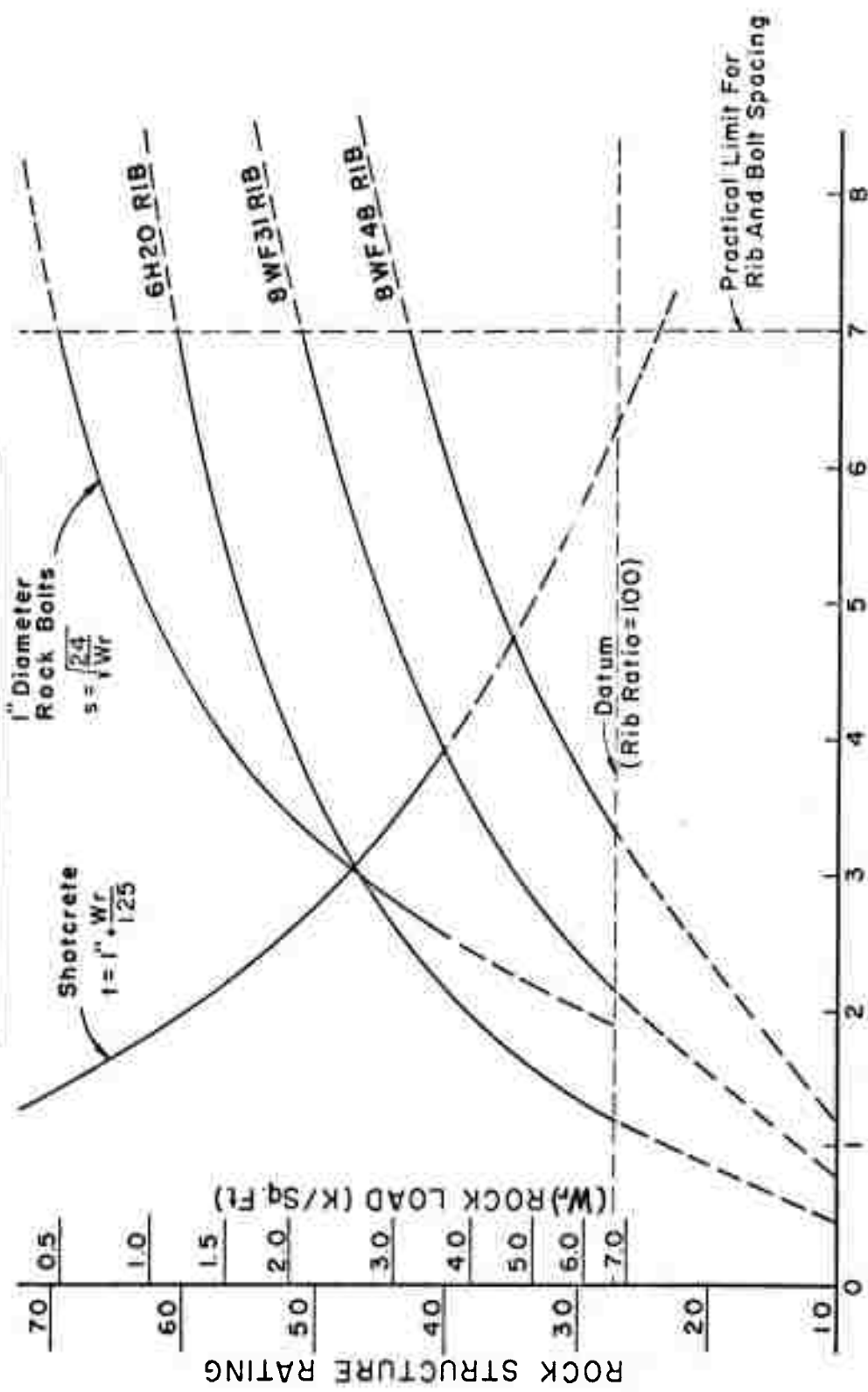
RIB SPACING (Ft.)
BOLT SPACING (Ft.×Ft.)
SHOTCRETE THICKNESS (In.)

20' DIAMETER TUNNEL

Figure 1.3

1.3 Research Work - Phase II

The work previously performed is being extended with additional empirical, theoretical and experimental capability to confirm, expand, or modify the ground support prediction model known as the Rock Structure Rating (RSR) concept.

Particularly, this contract will extend prior work to areas of limited data. Additional case studies are being investigated to supplement those previously used to formulate the Rock Structure Rating support prediction method. These include mining projects and tunnels reinforced by rock bolts and shotcrete. Selected firms and individuals prominent in the tunneling industry are being asked to review and critique the work performed to date. The finalized prediction method will be used in field application to predict required supports for ongoing projects and subsequently compared to supports actually used.

1.4 A.R.P.A. Implications

The principal purpose of this work is to improve current practices in tunneling, and in particular the primary support sub system, by reducing contingencies in the pre-construction stage. Improved definition of support system functions and requirements will aid in suggesting and evaluating new support methods for rapid excavation.

2.0 ADDITIONAL CASE STUDIES

2.1 General

To date, five additional tunnels have been analyzed to obtain case history data to supplement those used to develop the RSR concept. The general characteristics of these tunnels are given in Fig. 2.1. The computed RSR and RR values for various geologic sample sections are given in Fig. 2.2. These points have been plotted on a graph similar to Fig. 1.2. The original curve and 90% envelope has been superimposed for comparison. (See Fig. 2.3) The original points shown on Fig. 1.2, have been omitted for clarity. The individual projects are discussed briefly below.

In addition to these five tunnels, data for ten diversion and outlet tunnels was made available by the Corps of Engineers, Omaha District. Several of these are supported wholly or in part by rock bolts, which will add important data to the overall concept. After analysis of the new case studies, all appropriate points will be added to those previously plotted, and a new composite curve will be developed which will be presented in the final report.

2.2 Berkeley Hills Tunnel

This tunnel was constructed for the San Francisco-Bay Area Rapid Transit District, in 1965-67. The excavation was a twin bore, 21ft. modified horseshoe, each 16,200 feet long and driven through a series of folded, faulted sedimentary formations. Near the west end, the tunnels pass through the Hayward Fault. Pre-construction geologic investigations were very thorough, including over 2400 L.F. of instrumented drifts. In addition, ground support information was available from the nearby and previously constructed Caldecott Tunnels. Steel rib support at a maximum of 4' centers was specified

CASE HISTORY STUDY PROJECTS

CASE HISTORY NO.	NAME OF TUNNEL	LOCATION	SIZE OF EXCAV. SECTS.		TOTAL LENGTH L.F.	NO. OF STUDY SECTIONS	METHOD OF EXCAV.
			DIMENS.	SQ. FT.			
34	Berkely Hills	Calif.	21x21 HS	370	16,200	9	D&B
35	Poe (partial)	Calif.	23x23 HS	470	17,600	5	D&B
36	Balboa Outlet	Calif.	16 Dia.	200	3,800	2	TBM
37	McCloud No. 1	Calif.	17x17 HS	260	11,200	5	D&B
38	McCloud No. 2	Calif.	17x17 HS	260	25,600	9	D&B

Figure 2.1

			RSR DETERMINATION				SUPPORT		
CASE NO.	TUNNEL SIZE (Ft.)	ROCK TYPE	A	B	C	TOTAL	SIZE	SPACE	RIB RATIO
34-1	21x21 HS	2	12	20	15	47	8WF40	4.0'ctrs.	63
-2		2	8	18	6	32	8WF40	2.0'ctrs.	126
-3		2	12	18	7	37	8WF40	2.1'ctrs.	119
-4		2	12	19	12	43	8WF40	2.6'ctrs.	97
-5		2	12	24	15	51	8WF37	3.8'ctrs.	62
-6		2/1	15	24	12	51	8WF37	3.6'ctrs.	64
-7		2	8	24	15	47	8WF37	2.9'ctrs.	82
-8		2/1	13	22	12	47	8WF37	4.0'ctrs.	59
-9		2	12	18	12	42	8WF37	3.8'ctrs.	61
35-1	23x23 HS	3	22	38	20	80	None	-	0
-2		3	14	30	15	59	8WF20+	5.8'ctrs.	18
-3		3	22	30	12	64	8WF18+	6.3'ctrs.	16
-4		3	14	15	15	44	8WF24+	3.1'ctrs.	43
-5		3	14	30	15	59	8WF20+	6.2'ctrs.	17
36-1	16 Dia.	2	20	18	12	50	Shotcrete	3-1/2"Th.	59
-2		2	20	18	7	45	Shotcrete	3-1/2"Th.	59
37-1	17x17 HS	2	20	20	14	54	4WF13+	4.7'ctrs.	21
-2		2	20	25	15	60	4WF13+	5.8'ctrs.	14
-3		3/2	23	12	10	45	6WF20+	3.9'ctrs.	33
-4		3	22	30	18	70	4WF13	5.1'ctrs.	16
-5		2	12	12	15	39	4WF13+	2.1'ctrs.	40
38-1	17x17 HS	2	12	34	15	61	4WF13+	3.7'ctrs.	22
-2		3/2	13	27	6	46	4WF16+	3.4'ctrs.	33
-3		3	22	25	19	66	4WF13+	8.5'ctrs.	10
-4		3/2	13	24	7	44	4WF16+	4.0'ctrs.	26
-5		3	14	25	17	56	4WF13+	4.8'ctrs.	18
-6		3	14	20	12	46	6WF20+	4.0'ctrs.	36
-7		3	14	32	18	64	4WF13	5.8'ctrs.	14
-8		3/2	13	24	9	46	4WF13+	3.1'ctrs.	29
-9		2	12	37	15	64	4WF13+	4.0'ctrs.	21

ROCK STRUCTURE RATINGS AND RIB RATIOS
DETERMINED FOR CASE STUDY TUNNELS

Notes: Rock Type: 1) Igneous 2) Sedimentary 3) Metamorphic
8 WF 28+ indicates size most prevalent in this area of
tunnel (more than one size used)

Figure 2.2

Figure 2.3

RIB RATIO (RR)

ROCK STRUCTURE RATING (RSR)

ORIGINAL CASE STUDIES

ADDITIONAL CASE STUDIES:
+ BERKELEY HILLS
□ POE (PARTIAL)
△ BALBOA OUTLET
● McCLOUD NO.1
○ McCLOUD NO.2
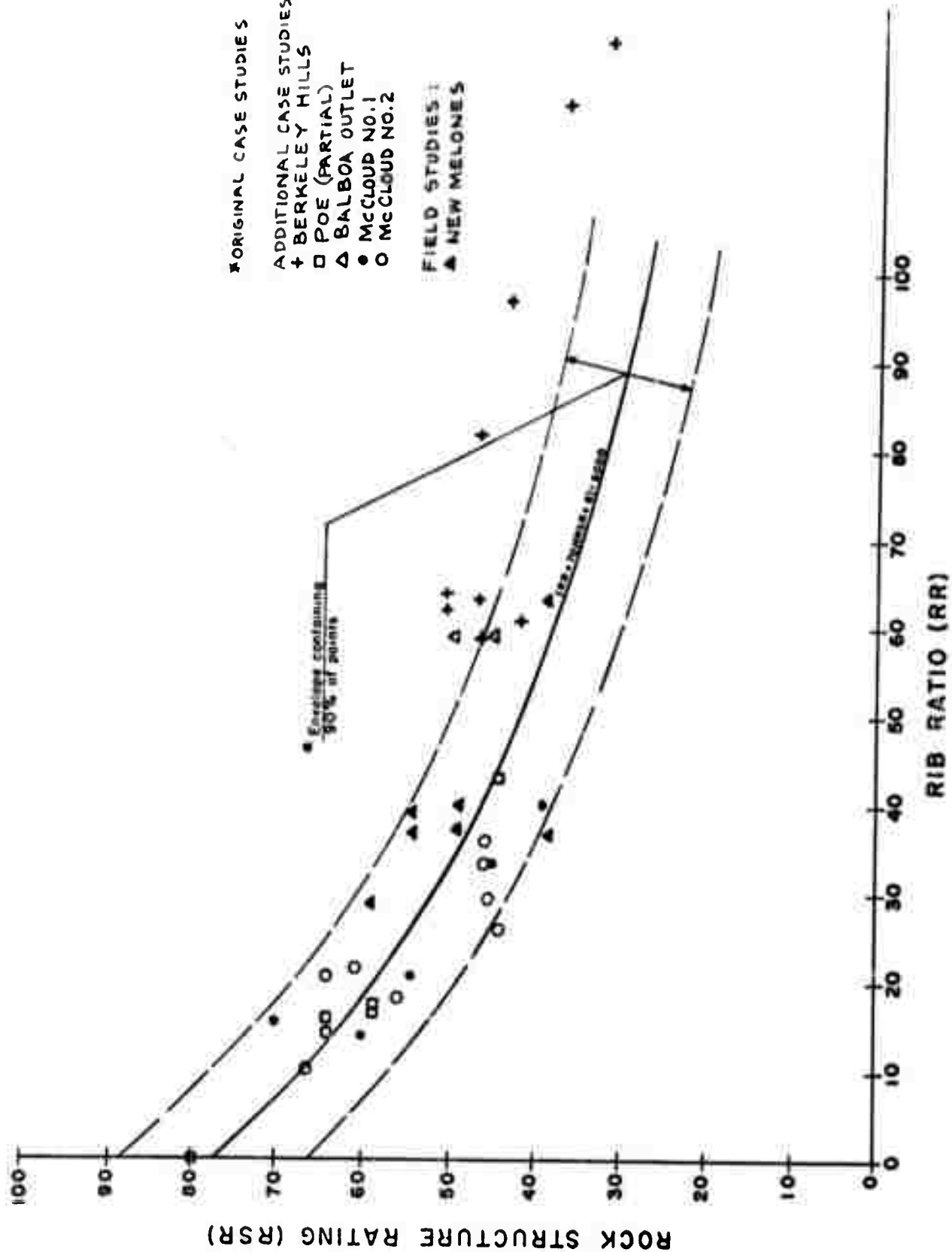
FIELD STUDIES:
▲ NEW MELONES

Envelope containing
90% of points

2-4

throughout the tunnel. This spacing was reduced going through the Hayward Fault zone and other difficult areas. The tunnels were completed without any major difficulties. As seen on Figure 2.3, the plotted RSR and RR values determined for this tunnel are above the 90% envelope.

2.3   Poe Tunnel (partial)

The Poe Tunnel was constructed for the Pacific Gas and Electric Company (P.G. & E.) in 1955-57. Case history data for about 15,100 feet of this tunnel was available, in Phase I. Data for the remaining 17,600 feet of this tunnel is now available and is being used to provide five additional geology-support sample sections. This tunnel was driven as a 23 foot horse-shoe through metamorphic rock. Fig. 2.3 shows each of the plotted points within the original 90% envelope.

2.4   Balboa Outlet Tunnel

This 3800 foot tunnel was excavated by a boring machine. It was driven 16 foot in diameter and was built in 1969 for the Metropolitan Water District of Southern California through sedimentary rock. The primary support is 3" to 4" of shotcrete lining. Although Fig. 2.3 shows this support as conservative in comparison to the other case studies, it is noted that a 68' section of shotcrete support failed during construction. This failure could be attributed to removal of invert shotcrete in the area rather than insufficient thickness of the arch.

2.5   McCloud Tunnels No. 1 & No. 2

These tunnels 11,200 foot and 25,600 fott respectively were driven through sedimentary and metamorphic rock in 1963-65. They were constructed in California for P.G. & E. and were excavated in a 17 foot horseshoe shape.

They have been sub-divided into five and nine sections respectively. As in the case of other P.G. & E. tunnels little preconstruction geology is available. The RSR and RR values are based on as-built geology data. The points plotted for these tunnels conform well to those of other case studies, as shown in Fig. 2.3.

3.0 INDUSTRY EVALUATION

3.1 Selection of Candidates

To be of value to the tunnel construction industry it is obvious that any new or proposed prediction method must be accepted by, and have the general concurrence of those involved; the owner, the engineer, the geologist and the contractor. Approximately thirty people, all prominent in the tunneling industry were asked to evaluate the work done to date and to offer suggestions on improvement. The initial contact was made on an individual basis, either in person or by phone. The response indicated a great interest in the problem of tunnel support and a willingness to cooperate.

To acquaint these people with the work that had been done to date, a summary report was prepared entitled "Rock Tunnel Support Determinations Based on Geologic Predictions". This consisted of three parts; the first being a copy of a paper presented at the Rapid Excavation and Tunneling Conference in Chicago, June 1972 (Ref. 3). This paper is a synopsis of the work done in Phase I, explaining the development and use of the Rock Structure Rating concept. The second portion consisted of RSR parameter tables (as in Fig. 1.i) and previously developed support requirement charts (See Fig. 1.3). The third section was a copy of Section 6 of the report (Ref. 1) wherein a hypothetical tunnel model was developed and the application of the RSR concept was illustrated.

3.2 Evaluation Questionnaire

In order to correlate responses, a questionnaire was prepared and sent to each candidate several weeks after initial contact. The questionnaire is divided into four parts: 1. General, 2. Geologic Factors,

3. Support Prediction Model, and 4. Acceptability of Proposed Rock Structure Rating. Questions are in various forms of multiple choice, including, where appropriate, rating of preferences by numerical sequence, and rating by percentages. It was felt that this would make response easier for those whose time is limited. Each part however had room for additional comments and this was specifically encouraged for those who could spend more time, or who wished to make suggestions, or to criticize any part of the work. Each of the persons contacted has had considerable experience in his field, and in addition to the summation of answers to the questions, the individual comments will be quite helpful. A copy of this questionnaire is given in Appendix A of this report.

3.3   Results of Industry Evaluation

The specific aims of this portion of the work includes:

1. Obtain opinions as to the acceptability of the RSR concept.

2. Obtain comments & evaluations on the relative values of the parameters used.

3. Obtain and correlate opinions of industry representatives on various aspects of geologic investigation and tunnel support.

4. To use the information obtained to modify the RSR concept.

At the end of the period covered by this report, ten of the twenty-nine questionnaires had been returned.

While it is too early to summerize results it is apparent that there is a general concern and interest in solving the problem of predicting tunnel support requirements. Each person returning the questionnaire had answered or commented on all or most of the questions. Each had made some comments in addition to the multiple choice answers. A complete summary and evaluation

of answers will be included in the final report. Several responses thought the RSR concept "a step in the right direction" but pointed out additional factors they felt should be included, such as "effect of in-situ stress field", "dynamic factors such as fault movement", "squeezing, swelling and running ground", "alluvium should be considered under rock (soil) types", etc. Each will be considered, and where possible, the finalized prediction model will be expanded to include consideration of these factors.

Some of the comments are not directly related to the physical aspects of ground support but should provide useful and interesting information to be considered in the overall ground support evaluation.

4.0 FIELD STUDIES

4.1   Joint Field Trips

This research includes field verification of the proposed tunnel support prediction model as a joint effort of contractor and Bureau of Mines Technical Project Officer. Ongoing Tunnel projects, mutually agreed on, are to be used for this purpose. Using available geologic data, RSR values are to be determined for various sections and prediction made of suitable support systems. As the construction proceeds, a comparison is to be made between actual supports used and those determined by the RSR method. Predictions made to date are based on the current RSR model and may vary when the final predictive model is completed.

Two field trips have been made to date by the joint team of Eugene Skinner, Technical Project Officer, for the U.S. Bureau of Mines, and Henry Tiedemann of Jacobs Associates. In July, they visited the U.S. Corps of Engineers, New Melones Tunnel near Sonora, California, and in October visited four sites in Colorado, the Norad Underground facilities extension, the Henderson mine haulage tunnel, the Amax Henderson molybdenum mine development and Straight Creek Tunnel. Trips to Washington, D.C. (Metro subway tunnels), Nevada (Carlin Canyon tunnels) and Idaho (Coeur d'Alene mining area) are planned for the spring.

4.2   New Melones Tunnel

This is a fairly large tunnel (30' x 34' horseshoe) and supported mostly by shotcrete. The tunnel is 3,770 feet long and is being constructed as a diversion tunnel for the Crops of Engineers, New Melones Dam. The excavation has been completed, and it is now possible to compare the predicted

supports with the actual installed support.

The rock in this area consists of almost vertical layers of meta-volcanic rock interbedded with meta-sandstone, slate, slate-breccia and serpentine. The rock is blocky to massive except in the several fault and shear zones where it is closely jointed and shattered. In most areas there is four inches of shotcrete in the arch and two inches on the sides. In the fault and shear zones the shotcrete support has been supplemented with steel ribs. The shotcrete has stood up well.

T'.e estimated and actual supports are compared on Fig. 4.1. The actual RSR-RR values have been plotted on the graph in Fig. 1.2, where they conform well to the current curve.

4.3   Cuajone Tunnels

The number of ongoing tunnel projects in the United States is presently unusually low. In order to extend the number of test studies for the prediction model it was decided to use overseas tunnel projects for which sufficient data was available to make the evaluations. One such project is the Cuajone Tunnels in Peru.

The project consists of a series of five railroad haulage tunnels for the Southern Peru Copper Corporation in the Departments of Moquegua and Tacna, Peru. Construction has begun on two of these tunnels, Cuajone No. 4, 48,400 feet long and Cuajone No. 5, 7,600 feet long. A geology report compiled prior to start of construction was used as a basis of support prediction requirements for these tunnels. This geology report was based almost exclusively on surface investigations. The predicted supports based on the RSR method will be compared with current progress reports which delineate as built conditions.

FIELD CASE STUDY NO. 1 - NEW MELONES TUNNEL

SECT	ESTIMATED		ACTUAL (EQUIV.) RR	* PREDICTED SUPPORTS			** ACTUAL SUPPORTS
	RSR	RR		STEEL RIBS	SHOTCRETE	1" ROCK BOLT PATTERN	
1	54	27	39	8 WF 40 @ 4-1/2'	3-1/2" Thick	3 x 3	4" Shotcrete (Some Ribs)
2	38	60	63	10 WF 49 @ 3'	6" Thick	2 x 2	6" Shotcrete (Some Ribs)
3	49	35	37	8 WF 40 @ 4'	4" Thick	2-1/2x2-1/2	4" Shotcrete (Some Ribs)
4	38	60	37	8 WF 49 @ 3'	6" Thick	2 x 2	2" Shotcrete & 8 WF 40 @ 5'
5	54	27	37	8 WF 40 @ 4-1/2'	3-1/2" Thick	3 x 3	4" Shotcrete
6	49	35	37	8 WF 40 @ 3-1/2'	4" Thick	2-1/2x2-1/2	4" Shotcrete
7	59	20	29	8 WF 40 @ 6'	2-1/2" Thick	3-1/2x3-1/2	3"± Shotcrete (Avg.)
8	49	35	40	8 WF 40 @ 4'	4" Thick	2-1/2x2-1/2	2" Shotcrete & 8 WF 40 @ 4'

* These are alternates - combined alternates were not determined because of the large number of possible combinations.

** Average, or most prevalent support in geologic section.

Figure 4.1

4.4   Metro Subway, Washington D.C.

Probably the largest tunnel project, involving soft ground and rock tunnels currently in progress in the United States, is the Metro subway system in Washington, D.C. Several contracts involving rock tunnels have been let and are in various stages of construction. The greatest length of rock tunnel in any one contract is section 1A0061 on the Rockville Route involving more than 18,000 feet of twin tube tunnels, a crossover section and exploratory drifts for three stations. This contract was slated for bidding in November 1972 and postponed till December. Besides its length, it was chosen for study because of its opportune scheduling, allowing for a determination of support requirements by RSR method during the pre-bid stage, prior to any construction. The predicted support requirements will be compared with actual, during course of construction.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Much valuable data has been added to the study through additional case studies, personal contact made possible by the industry evaluation, and by site visits and field application of the prediction model. It seems likely when all of these have been analyzed the prediction model will be modified and/or adjusted and expanded to broaden the use of the model and to relfect the experience and suggestions of concerned individuals.

While most of the responses received to date were favorable toward the RSR concept, the general concensus seemed to be cautious optimism rather than immediate acceptance. Like every other idea, it must be proven before it is to be widely accepted, and this is as it should be. Hopefully the field testing to be done under the remaining work of this contract will help in that direction.

5.2 Recommendations

While the work to be completed on this contract is aimed at producing a workable method for predicting rock tunnel supports prior to construction, it cannot be over emphasized that this is meant to be a flexible aid rather than a hard fast formula. Fashioned from experience, to remain useful, it must be periodically reviewed in light of new data. At present it should aid both the engineer and contractor in the preparation of their pre-bid estimates and help to reduce the contingencies in this item of work. Consideration should be given in the future to applying new techniques to update this concept, including: long horizontal boreholes, seismic or accoustical investigations, and instrumentation of support systems. These will go far in turning an "Art" into a Science.

REFERENCES

1. Wickham, G.E. and H.R. Tiedemann, (1972) <u>Research in Ground Support and its Evaluation for Coordination with System Analysis in Rapid Excavation</u>, Final Report Contract H0210038, ARPA Order 1579, distributed by Clearinghouse, U.S. Department of Commerce, Washington, D.C. as, AD 743100

2. Terzaghi, K. (1946) "Introduction to Tunnel Geology in R.V. Proctor and T.L. White, <u>Rock Tunneling with Steel Supports</u>, The Commercial Shearing and Stamping Co., Youngstown, Ohio

3. Wickham, G.E., H.R. Tiedemann and E.H. Skinner, (1972) "Support Determinations Based on Geologic Predictions", Chapter 7, Volume I of <u>Proceedings, North American Rapid Excavation and Tunneling Conference</u>, A.I.M.E., New York, pp. 43-64

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APPENDIX A

ROCK STRUCTURE RATING EVALUATION
QUESTIONNAIRE FORM

ROCK STRUCTURE RATING CONCEPT EVALUATION

I. <u>General</u>

1. Predicting ground support involves consideration of many factors or criteria drawn from different disciplines. Please rank the following with a weighted % (on a scale of 100%) as to the most frequently used criteria on which you have based your past prediction of ground support.

Pre-bid geology	_____ %
As-built geology (nearby projects)	_____ %
Past Tunneling experience	_____ %
Personal judgement	_____ %
Empirical relationship	_____ %
Rules-of-thumb	_____ %
Theoretical analysis	_____ %
Others	_____ %
	_____ %
	100 %

2. To establish a correlation between pre-bid geology and ground support would you: (Check most appropriate choice) _____ a) Include or make allowance for <u>all</u> available geologic information. _____ b) Use a <u>general</u> approach considering only major geologic factors.

3. In your opinion, what is the <u>minimum</u> geologic data that should be provided in the pre-bid period for the purpose of determining tunnel support?

_____

_____

_____

4. Rank in order of preference (1st, 2nd, etc.) the following investigation techniques which you believe provide the most meaningful information for predicting ground support (assume amount of detail provided by each to be compatible with present day investigation capabilities).

Vertical Borings and Logs	_____
Surface Geology	_____
Historical Geology	_____
Seismic Surveys	_____
Laboratory Testing of Samples	_____
Other	_____

5. Do you believe that the state-of-the-art for making geological investigations is <u>adequate</u> to provide information needed to make a reliable prediction of ground support?

Yes _____   No _____

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6. Should the projection of surface geology to tunnel grade be provided in pre-bid documents?

   Yes _____   No _____

7. Should the type, spacing and locations of anticipated support be included in pre-bid documents?

   Yes _____   No _____

8. Supports are sometimes installed for reasons other than geological considerations. In your opinion what percent of support is placed for the following reasons?

Actual ground requirements	_____ %
Potential safety hazards	_____ %
Expedient to tunnel driving	_____ %
Construction methods	_____ %
Other considerations	_____ %
Total Support Installed for typical tunnel project.	100 %

9. Additional comments on part 1. General _____

   _____

   _____

   _____

   _____

   _____

   _____

II. Geologic Factors

1. The need for ground support is dependent on and/or related to, various geological factors or conditions which individually or collectively affect the physical quality of the rock structure. Rank the following with a weighted % (on a scale of 100) as to the most important factors to be considered in describing the quality of a rock structure with respect to its need for support.

Geologic Factor	Symbol	Weighted Values
Rock Type-Lithologic Classification	(RT)	_____ %
Joint Orientation-Strike and Dip	(JO)	_____ %
Degree of folding or faulting	(RF)	_____ %
Rock Properties-Hardness etc.	(RP)	_____ %
Joint pattern-Spacing & Orientation of fractures	(JP)	_____ %
Geologic Structure	(GS)	_____ %
Condition of joint surfaces	(JS)	_____ %
Ground water inflow	(WF)	_____ %
Weathering or alteration	(WA)	_____ %
Other	( )	_____ %
		100 %

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2. The effect of geologic factors on the support requirement is usually dependent on other <u>characteristics</u> of the rock structure. In your opinion, which of the factors shown in 1-above must be considered <u>collectively</u> to properly describe their effect on the support requirement. Please indicate grouping of factors by symbol (i.e. ground water inflow and condition of joint surfaces - WF+JS -- etc) in the left hand column. Show in the right hand column the weighted value you would assign to each grouping with respect to their combined effect on the support requirement.

Geologic Factor Grouping	Relative effect on Support Requirement
_____	_____ %
_____	_____ %
_____	_____ %
_____	_____ %
_____	_____ %
_____	100 %

3. Various descriptive and quantitative terms have been used to define rock properties or geologic conditions which affect the rock structure and which are considered in making predictions of ground support. Within the general context of support determination, please, indicate your preference (1st, 2nd, etc) as to most appropriate means of describing the following geologic factors.

Rock Type

a. Igneous-Sedimentary-Metamorphic
b. Classification by subdivision and formation _____
c. Composition, texture, color, geological age etc. in addition to info in (b) _____
d. Other _____

Geological Structure

a. Massive-intensely folded or faulted etc. _____
b. Origin and sequence, geologic age, etc. _____
c. Other _____

Joint Spacing (Predominant Set)

a. Descriptive (Massive, blocky, intensely jointed, etc.)
b. Quantitative (2", 2" - 6", etc.) _____
c. Other _____

Joint Condition

a. Descriptive (fresh, weathered, stained, etc.) _____
b. Quantitative (i.e. 1/4" wide with clay gouge) _____
c. Other _____

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ROCK STRUCTURE RATING CONCEPT EVALUATION

Ground water inflow

a. Descriptive (Damp, Light Flow, etc.)
b. Quantitative (Anticipate about 50 gpm/1000 L.F.)   _____
c. Other _____   _____

Mechanical Properties of Rock Material

a. Descriptive (Medium to hard limestone)
b. Uniaxial Compressive Strength (i.e. 18,000 psi)   _____
c. Other _____   _____

4. Additional comments on Part II Geologic Factors

_____
_____
_____
_____
_____
_____

III. Support Prediction Model

Jacobs proposed prediction model (RSR concept as described in the R. E. T. C. paper on page 9) rates the competency of a rock structure on a numerical scale by evaluating three general parameters, each with respect to several geologic factors and where applicable with respect to each other. RSR ratings were determined and correlated with actual support installations for approximately 120 sample tunnel sections. Empirical relationships were developed which identifies typical support installations with anticipated rock conditions. (See RETC paper presentation (pages 9 thru 16) previously mailed to you).

1. Do you believe the most essential geologic factors have been included in the RSR evaluation? Yes _____ No _____

2. In your opinion, what additional factors should be included?

_____
_____
_____

3. What relative values would you assign to Parameter "A" _____ Parameter "B" _____ Parameter "C" _____ (See Appendix A of R.E.T.C. paper)

4. Do you believe the weighted values assigned to specific combinations of geologic factors and conditions as shown on tables for Parameters "A", "B", "C" reasonably reflect differences in support requirements?

Yes _____ No _____

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ROCK STRUCTURE RATING CONCEPT EVALUATION

5. Do you believe that pertinent features or physical condition of rock structure can be properly identified on a numerical scale?

Yes _____ No _____

6. Do you believe that an empirical relationship between geologic factors and support requirements can be developed which would be adaptable to most rock tunnels?

Yes _____ No _____

7. Rate the following in order of preference (1st, 2nd, etc.) as to type of information you would most heavily rely on in developing a support prediction model.

    Improved investigation techniques   _____
    Empirical relationships based on past experiences   _____
    Theoretical analysis of rock mechanics   _____
    Rules-of-thumb   _____
    Insitu testing   _____
    Data Banks   _____

8. Additional comments on part III Support Prediction Model _____
_____
_____
_____
_____
_____
_____

IV. Acceptability of Proposed Rock Structure Rating

Any proposed scheme of rock structure classification for support prediction must ultimately have industry acceptance.

1. Please rate in order the segment (s) of industry you believe would most benefit from any concept of Rock Structure Rating.

    Federal or State owner agencies   _____
    Private owners, i.e. utilities   _____
    Owners A & E representatives   _____
    Design engineers   _____
    Geologists   _____
    Contractors   _____

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2. Do you believe such a concept would improve or worsen the following:

	Improve	No Effect	Worsen
Owner-engineer relationship	_____	_____	_____
Owner-geologist relationship	_____	_____	_____
Owner-contractor relationship	_____	_____	_____
Changed Condition Clauses	_____	_____	_____
Contract Price	_____	_____	_____

3. Do you believe such a concept would increase or decrease responsibilities of the following groups in the tunneling industry?

	Increase	No Effect	Decrease
Owner's responsibility	_____	_____	_____
Engineer's responsibility	_____	_____	_____
Geologist's responsibility	_____	_____	_____
Contractor's responsibility	_____	_____	_____

4. It is probable that in the future, advanced techniques in instrumentation or geologic investigations will enable us to get an accurate model of the actual rock loads imposed on a support system. Any support prediction model, to be useful in the future, should be adaptable to this type of data input as it is developed. Do you believe the proposed Rock Structure Rating concept as proposed is adaptable to such change?

Yes _____ No _____

5. Additional comments on part IV. Acceptability of Proposed Rock Structure Rating _____

_____
_____
_____
_____
_____
_____

_____
Name

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